PASSIVE ATTITUDE CONTROL OF A SPIN-STABILIZED SPACECRAFT BY SOLAR RADIATION PRESSURE ON CANTED VANES

Final Report

JPL Task 919

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A. OBJECTIVES

The objective of this task is to determine the feasibility of an alternate attitude control system, based on solar radiation pressure on simple vanes fixed to a spin-stabilized spacecraft, that uses no consumable resources and thus offers potentially unlimited mission lifetimes. Efforts to reduce the mass or extend the lifetime of some space flight missions hinge on the mass of attitude determination and control systems, and the amount of attitude control propellant the spacecraft can carry. This has been a roadblock for envisioned missions involving multiple small, simple spacecraft in heliocentric or sun-synchronous Earth orbit that might have such science objectives as near-side and far-side solar activity monitoring, heliospheric monitoring, etc. Freeing such missions of the cost, mass, and consumables constraints of standard attitude control methods would make them economically much more attractive to NASA and industry.

B. PROGRESS AND RESULTS

My analysis, which is now complete, used fundamental principles of physics (geometric optics and mechanics) to calculate forces applied by sunlight to a system of vanes fixed to a spinning spacecraft as illustrated in Figures 1 and 2, and the response of the spacecraft to those forces and the resulting torques. Major conclusions include:

(1) The method works. A wide range of vane configurations yield torques that precess the spacecraft's spin axis toward sunpointing. Although unable to move the axis to exactly sun-pointing, a vane system can produce a precession rate matching heliocentric angular rates with only a few degrees offset from sun-pointing. The proper torques arise primarily from photons absorbed by the vanes, so "black" vanes are desired. The sizing relation for the vanes on a given spacecraft is

$$Ar_v = \frac{2R^2 L n_{sun}}{S_c \sin\kappa \tan\delta}$$

where A is the total (one-sided) surface area of the vanes, r_v is the distance from the vanes' centroids to the spacecraft spin axis, R is heliocentric radius, L is the magnitude of the spacecraft's spin angular momentum, n_{sun} is the spacecraft's angular rate of orbital motion around the sun, S_c is the solar light pressure on a perfectly absorbing surface normal to the sun direction at 1 AU (~4.6 x 10^{-6} Nt/m^2), κ is the "cant angle" of the vanes, and δ is the desired spin axis' equilibrium angular offset from sun-pointing, as illustrated in Figure 3; this equation is valid for $\kappa + \delta < p/2$. For example, a 10 kg spacecraft ("Tuna can" shaped, ~40 cm diam.) in a 1 AU heliocentric orbit, spinning at 3 RPM, would need four 15 cm x 15 cm vanes, centered 40 cm from the spin axis, to maintain the spin axis within 20° of sun-pointing. For solar cells on the sunlit face of the spacecraft, that offset yields a cosine loss of ~6%. Increasing the vane size to 22 cm x 22 cm decreases the equilibrium solar offset angle to 10°.

(2) The torques that precess the spin axis act to slowly despin the spacecraft.

(3) Parasitic torques arising from the non-zero reflectivity of real vanes also act to despin the spacecraft. For small (a few degrees) pointing offsets, the magnitudes of these torques are larger than those in (2) above.

(4) There are multiple methods, involving no use of spacecraft-provided energy or consumables, to counter the despin torques mentioned above. These methods rely on smaller, specularly-reflecting "spin-up" vanes.

(5) For a fixed spacecraft geometry, total vane area scales as mass to the 4/3 power while spacecraft area scales as mass to the 2/3 power: as mass increases, the relative vane size increases. Eventually the vanes become sufficiently large that their mass is comparable to the spacecraft mass, and present packaging problems in small launch vehicle fairings.

C. SIGNIFICANCE OF RESULTS

The results of this task show that it is possible to maintain a small (up to tens of kg, maybe up to 100 kg), spin-stabilized spacecraft in a quasi-sun-pointing attitude for an indefinite period using a lightweight system of vanes. This enables a class of small, low-cost, long-lived spacecraft that, for example, monitor the Sun and heliosphere. A flotilla of such small spacecraft could be launched from a single small launch vehicle and deployed such that the flotilla spreads in a nearly one-AU heliocentric orbit ahead of or behind Earth's position. Eventually these long-lived spacecraft would form a loose ring around the sun, viewing it from many positions. The many spacecraft could establish a data relay network (possibly autonomous?), relaying data from spacecraft to spacecraft toward Earth until the one nearest Earth performs the final downlink.

D. FINANCIAL STATUS

The total funding for this task was $25,000, of which $11,000 has been expended.

E. PERSONNEL

No other personnel were involved.

F. PUBLICATIONS

None. I did not want to publish anything that might interfere with patentability.

G. REFERENCES

None. All work began with fundamental physics.

H. APPENDIX: *FIGURES*

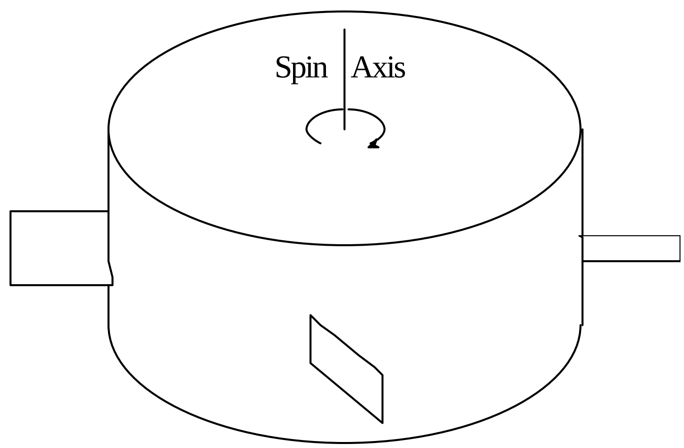

Figure 1: Gross System Geometry. This oblique view shows three vanes of an example four-vane system. The spacecraft is modeled as a short "tuna can" cylinder.

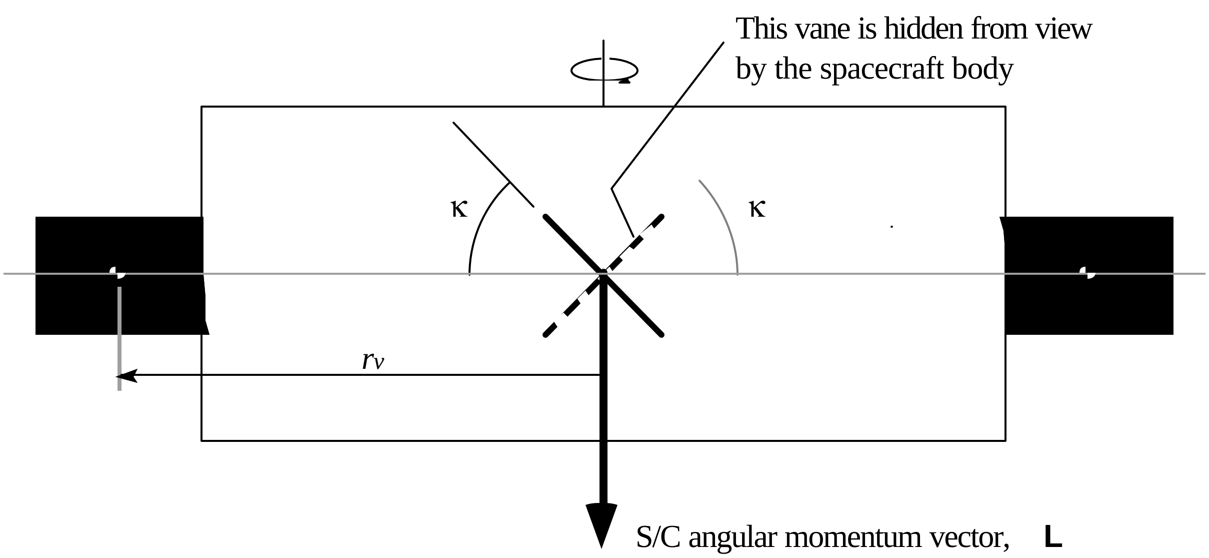

Figure 2: Vane Specifications. This side view illustrates the vane "cant angle" κ, and the distance from the spin axis to the vanes' centroids.

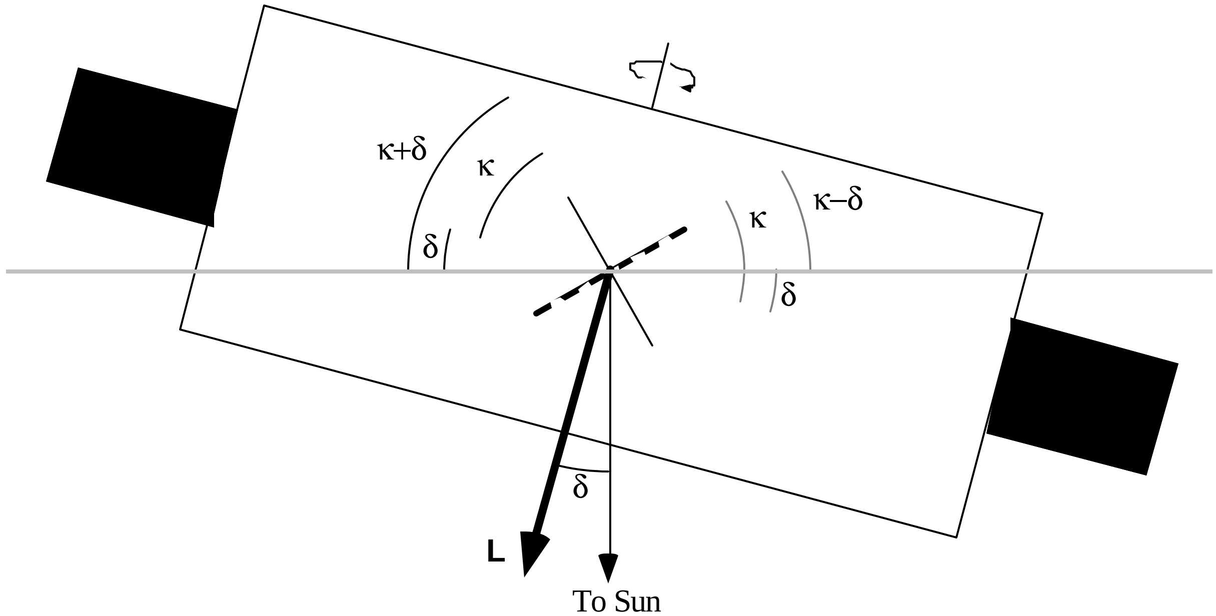

Figure 3: Off-Sun Pointing. This side view shows the effect of off-sun pointing. Note that the hidden vane (dashed line in the center) offers a larger projected area to the sun than the near-side vane, yielding higher solar light pressure on a vane in that position and thus an unbalanced torque. This unbalanced torque precesses the L vector toward sun-pointing.